US005131970A

United States Patent [19]

Potter et al.

[11] **Patent Number: 5,131,970**

[45] **Date of Patent: Jul. 21, 1992**

[54] **BLOCK-BONDED PROCESS FOR PRODUCING THERMOPLASTIC RESIN IMPREGNATED FIBER HONEYCOMB CORE**

[75] Inventors: **John E. Potter**, Camarillo; **John A. Van Hamersveld**; **Norma J. Cretal**, both of Thousand Oaks, all of Calif.

[73] Assignee: **Northrop Corporation**, Los Angeles, Calif.

[21] Appl. No.: **488,582**

[22] Filed: **Mar. 2, 1990**

[51] **Int. Cl.**[5] **B32B 3/12**

[52] **U.S. Cl.** **156/205; 156/264; 428/118**

[58] **Field of Search** 428/116, 118; 156/205, 156/207, 264

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,821,616	1/1958	Spott	428/116 X
2,919,472	1/1960	Steele	156/197 X
3,673,058	6/1972	Jackson et al.	428/118
4,179,540	12/1979	Smarook	521/98 X
4,457,963	7/1984	Ittner et al.	428/34.1
5,021,283	6/1991	Takenaka et al.	428/118 X

FOREIGN PATENT DOCUMENTS

WO87/06186	10/1987	PCT Int'l Appl.	428/116

Primary Examiner—Henry F. Epstein

Attorney, Agent, or Firm—Terry J. Anderson; Robert B. Block

[57] **ABSTRACT**

Ultra strong lightweight core material capable of sustained operation at unusually high temperatures for composite structure of the type used in aircraft parts such as wings, fairings and stabilizers is produced from preimpregnated thermoplastic fibercloth ribbon by the manufacturing processes of this invention. The fibercloth ribbon is preformed between corrugated rollers of a special roll forming press which heats the ribbon to a softening temperature, forms it into a pattern of half-hex corrugations, cools it and sets it in that pattern. Then sheets cut from the corrugated ribbon are stacked into a bonding press along with hex forming mandrels placed between the sheets in the corrugations. With a full stack, the press is enclosed with side covers containing heating units, hydraulic pressure is applied to compress and consolidate the stack and contact interfacial facets, and heat is applied by directing superheated air jets on the mandrel ends until a bonding temperature is reached, forming the material accurately around the hex mandrels and fusion bonding adjacent sheets together at interfacial facets in a honeycomb pattern. After cooling to a setting temperature, pressure is removed and the bonded stack is removed from the bonding press. The mandrels are then extracted in a special long stroke thin pin pneumatic press, yielding a finished block of lightweight core material having a honeycomb pattern of hex ducts with rigid walls.

3 Claims, 2 Drawing Sheets

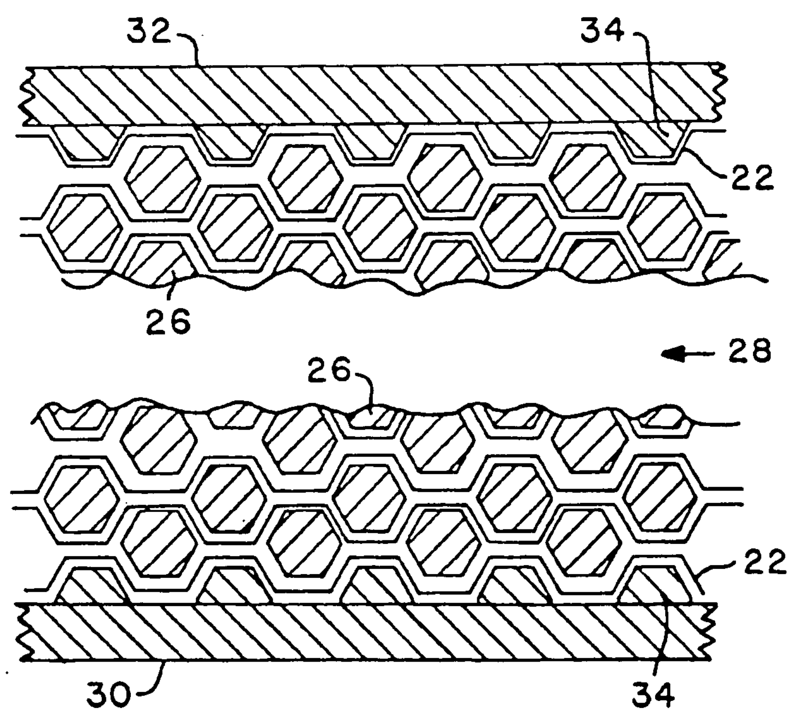


FIG. 1

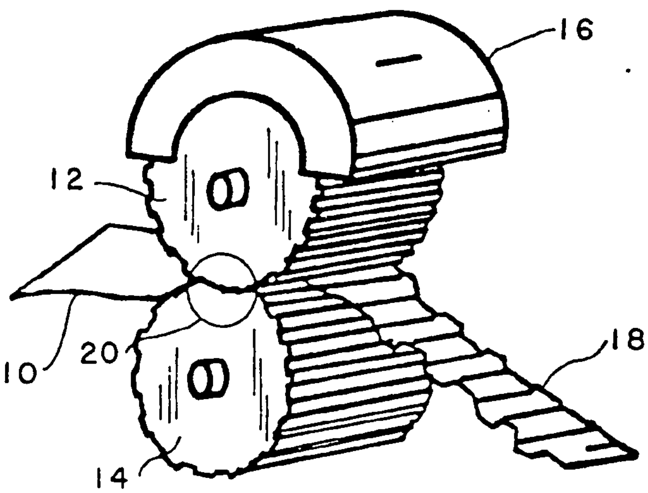


FIG. 2

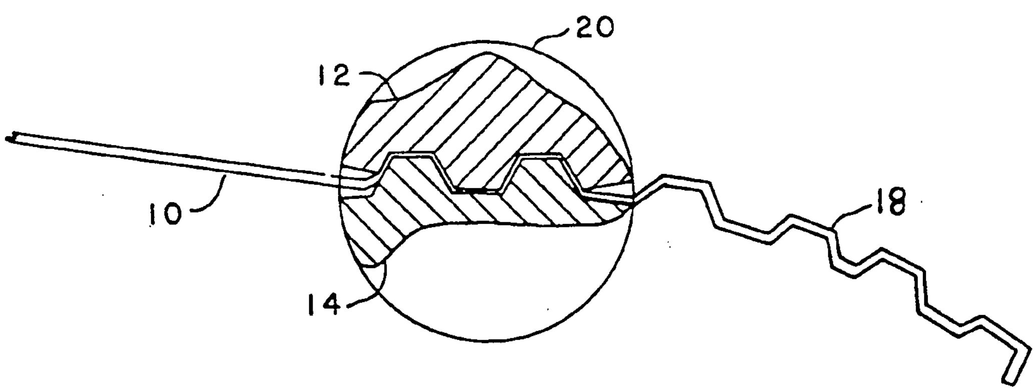


FIG. 3A

FIG. 3C

FIG. 3D

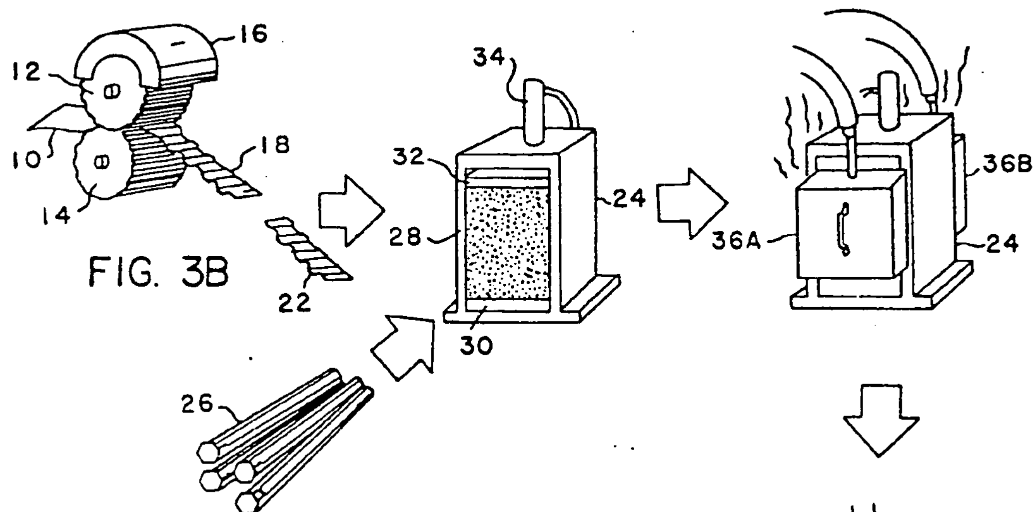
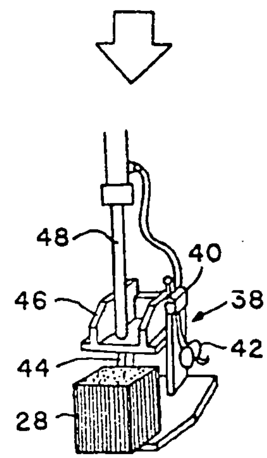


FIG. 3B

FIG. 3E



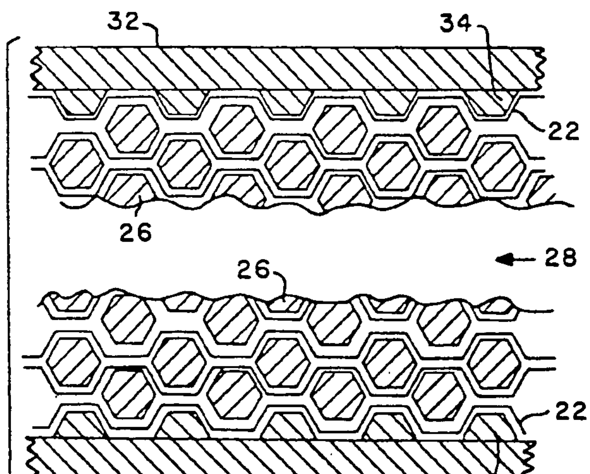


FIG. 4

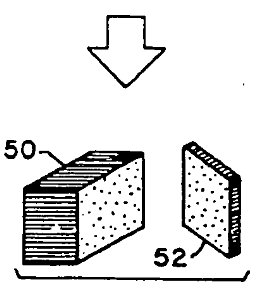


FIG. 3F

BLOCK-BONDED PROCESS FOR PRODUCING THERMOPLASTIC RESIN IMPREGNATED FIBER HONEYCOMB CORE

FIELD OF THE INVENTION

This invention relates to the production of ultra strong lightweight core material for composite structures as used in aircraft, and more particularly to processing preimpregnated thermoplastic fiber cloth material to yield a block of ducted honeycomb core material capable of sustained high temperature operation.

BACKGROUND OF THE INVENTION

Composite structures in aircraft typically utilize a tough skin surface supported by a lightweight core material. Development efforts to increase the strength/weight ratio of the core have resulted in cellular plastic structures such as rigid expanded foam of random cell pattern. Superior structural properties have been realized in cores formed in a geometric honeycomb pattern of hexagonal ducts, which achieve very light weight due to the high percentage of air volume in the range of about 90% to 98%. Such a core, when sandwiched between two skins, forms a directional structure possessing a uniform crushing strength under compression.

In known art, cellular or ducted cores are commonly made from thermosetting resins. As utilization of such structures is expanded to include areas previously avoided due to structural demands and temperature, vibration and impact loading environments, new composite matrices are required. Thermosetting resins, commonly used, in most cases, lack the toughness and stability needed for these applications.

New thermoplastic materials offer improved properties and excellent impact strength and damage tolerance are realized in composite skin-surfaced structures having honeycomb cores made from fiber cloth preimpregnated with thermoplastic resin. However, by their nature, the new thermoplastic materials require new and unconventional processing methods as opposed to conventional thermosetting processes where viscous fluids are saturated into reinforcing fiber forms to be cured by catalysis and heat, thermoplastics, which have no cure cycle, are hard and "boardy" initially, and have to be melted at high temperatures to be worked to the desired shapes. Thus completely different processing schemes are required for thermoplastics than those that have been developed for thermosets.

In known art, thermoset honeycomb material is made by a process that takes advantage of the flexibility of the reinforcing fabric before it is impregnated with resin. It is bonded and then expanded into hexagon honeycomb structure while it is soft, then wash coated with resin which is subsequently cured to give it its stiffness.

In contrast, most thermoplastics are too viscous to be wash coated or by some other means saturated into the fabric after bonding sheets or ribbons together. The practical options for bonding thermoplastic core material together are further limited by the difficulty of making good adhesive bonds with thermoplastics. For these reasons, thermal forming and assembly of preimpregnated thermoplastic material by thermal fusion ducted honeycomb structural pattern has been selected as the method for producing strong lightweight core structure in the present invention, which addresses new processing methods for realizing the full benefits of the superior ultimate properties of such structure.

OBJECTS AND SUMMARY OF THE INVENTION

A primary object of this invention is to provide a method of producing thermoplastic honeycomb core that can be used at sustained high service temperatures without substantial loss of strength or degradation of mechanical properties.

A further object is to provide a method and apparatus for forming corrugations of half hex pattern in a preimpregnated thermoplastic fiber ribbon.

A further object is to provide a method and apparatus for thermal fusion bonding the interfacial facets of a stack of preformed sheets cut from corrugated thermoplastic fiber ribbon, so as to produce a block of hex ducted honeycomb patterned core material.

A still further object is to provide a process and pressing apparatus for removing hexagon aluminum mandrels from a stack of corrugated thermoplastic fibercloth sheets bonded in accordance with this invention, as a final step in producing a block of honeycomb core material.

These objects have been met in the processes and apparatus of this invention which will be described in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a heated roller press in the process of corrugating a thermoplastic fiber ribbon in accordance with present invention.

FIG. 2 is an enlarged view of the active forming region of FIG. 1.

FIGS. 3A-3F comprise a schematic diagram of the overall process of manufacturing a block of honeycomb core from thermoplastic fiber ribbon in accordance with the present invention, in which:

FIG. 3A shows the corrugating step;

FIG. 3B shows the cutting step to form strips;

FIG. 3C shows the stacking and mandrel insertion steps;

FIG. 3D shows the layer fusing step;

FIG. 3E shows the mandrel extraction step; and

FIG. 3F shows a forming step being taken on the completed honeycomb product.

FIG. 4 is an enlarged side view of a portion of a stack of half hexagon formed sheets and hexagon mandrels, as loaded in the press at step C in FIG. 3 in preparation for bonding.

DETAILED DESCRIPTION

Returning now to the drawings in detail, FIG. 1 depicts a roll forming process of this invention in which presaturated thermoplastic fibercloth ribbon **10** is being corrugated between rollers **12** and **14** which are spring loaded against each other in a well known manner. A controllable heating unit **16** is disposed in a wrapped-around configuration close to the upper portion of upper roller **12** so as to heat it while the lower roller **14**, having no heat applied, remains relatively cool. With this arrangement, as the ribbon **10** is passed between the rollers **12** and **14**, the top roller **12** heats the material to a formable temperature and then, as the formed material **18** exits at a downward angle, the lower roller **14** cools it almost immediately to set it in its new shape.

The forming region **20** of FIG. 2 is enlarged in FIG. 3, showing the half hexagon teeth of upper roller **12** and

lower roller 14 meshing together to form the flat material 10 into corrugated material 18 having a half hex pattern.

The pictorial diagram of FIG. 3 illustrates the basic process steps of the overall method of this invention for manufacturing a block of honeycomb core material from thermoplastic fiber ribbon.

At step A, a flat ribbon 10 of thermoplastic fiber is corrugated between forming rollers 12 and 14 (as described in connection with FIGS. 1 and 2). The resulting corrugated ribbon 18 is then cut at step B into sheets of desired length, such as sheet 22 shown.

At step C, the sheets are stacked in a press 24. A hexagonal mandrel 26 is placed into each groove of the corrugations upon each sheet added to the stack, Mandrels 26 are typically made of metal such as aluminum and treated with a release agent to prevent sticking. The stack 28 is built up on a lower press platen 30 and, when full, pressed together by an upper platen 32, urged downwardly by a hydraulic cylinder 34.

The mandrel may be made of other thermal conductive metal or materials such as copper, or even steel, provided that the thermal conductivity is at least as large as that of the associated parts, i.e., the mold, the tools, and the hydraulic system that operates the same.

As shown in the enlarged end view of FIG. 4, the pressurized stack 28 forms a honeycomb pattern of rows of hex mandrels 26 interleaved between the corrugated sheets 22. Conformal support for the lower and upper sheets of the stack 28 is provided by half hex spacers 34 at the lower platen 30 and the upper platen 32.

Referring again to FIG. 3, at step D heat is applied by forced air heating assemblies 36A and 36B, secured to both sides of the press 24, to bring the stacked sheets up to a softening temperature to fusion bond the interfacial facets of adjacent sheets and accurately form hex ducts around the mandrels. After the heating cycle is terminated, pressure is maintained on the stack until it cools and sets; then it is removed from the bonding press 24.

Upon cooling, at step E the mandrels are removed individually from the bonded stack 28 using a special pneumatic long stroke mandrel extractor press 38 having a manually operated pressure control valve 40 and a flow steady pressure exerted by pin 44.

At step F, with the mandrels removed, the block 50 of bonded honeycomb core material may be machined or sawn into slices of desired thickness such as slice 52 shown, as finished core material ready to be incorporated into composite structure.

Particular parameters of the process depend on the type of material used, the honeycomb pattern size and the size of block to be produced; as an example, in FIG. 1, for a cubic block of core material having finished dimensions of about 6" (15.2 cm) on each side, rollers 12 and 14 are made 6.114" (15.53 cm) outside diameter and about 8" (20.3 cm) wide to form 6" (15.2 cm) wide material. For a hexagon duct width of 3/16" (0.1875", 4.76 mm) the roller tooth configuration in FIG. 2 is made 0.109" (2.769 mm) at the plateau and 0.120" (3.048 mm) at the valley floor at a depth of 0.094" (2.388 mm), for PAS-2 material having a typical thickness of 0.01" (0.254 mm). Cooling and setting of corrugated material 18 may be expedited by directing cool air from a row of jets onto its surface as it exits the roller interface.

The core bonding press 24 in FIG. 3 is designed to exert up to 200 psi across the total sheet area of the core block. The press structure is constructed of machined and ground steel plates. The vertical sides are spaced to allow an even multiple of the width of 19 cells which equals 6.384" (16.22 cm). The aluminum press platens 30 and 32 close in a range to compress a 6" (15.2 cm) high stack of ribbons and hexagon mandrels. The press platens 30 and 32 are machined to provide the half hex spacers 34 in FIG. 4; alternatively separate half hex spacers 34 could be laid in individually, optionally fastened to flat platen surfaces. Platens 30 and 32 are insulated from the rest of the press structure by Martensite sheets, on which they are mounted, to protect the hydraulic cylinders and oil from the high temperatures required to consolidate the core block. Pressure between the platens is provided from one or more cylinders 34 in a simple hydraulic system which may utilize a pressure gauge, a hand pump and a shut-off valve.

Regarding heat for core consolidation, since the thermoplastic does not actually cure it does not need to remain at the bonding temperature for any length of time. Furthermore, it is advantageous to heat up and cool off the assembly as rapidly as possible to prevent transfer of excessive amounts of heat to the hydraulic system. For these reasons a Moen type heater was selected as the heat source in units 36A and 36B: heat is rapidly transferred to the stack 28 by impinging air superheated air at very high velocities onto the ends of the aluminum mandrels 26 by air jets in distribution panels inside heating units 36A and 36B.

Extraction of the aluminum mandrels from the core ducts after fusion bonding as in FIG. 3, step E, can be difficult and tedious. Of particular difficulty is removing "stuck" mandrels without damaging the duct walls. The aluminum mandrels soften back to near "0" condition during the high temperature fusion bonding, so too much pressure from pushing or pounding will spall or "mushroom" the ends, and potentially damage the duct wall as it passes through. The special pneumatic press 38 developed in conjunction with the processes of present invention is provided with a special drive pin 44 which is 0.125" (3.175 mm) in diameter and has a travel of over 6" (15.24 cm). Pin 44 is supported by fixed and floating bushings to prevent buckling under pressure, enabling the mandrels to be pressed out with a steady, even, controlled downward pressure.

The above described method and apparatus of a particular illustrative embodiment discloses the best mode known for practicing the invention to produce core material in cubes in the order of 6" (15.2 cm) per side. The modification of certain parameters such as physical dimensions, press force, temperatures and timing of the processes taught by this invention, in order to optimally accomodate different sized work pieces and/or alternative equivalent materials are within the regular scope and competence of those skilled in the arts of plastic processing.

In a particular experimental embodiment the thermoplastic material used was polyethersulfone foam impregnated woven glass cloth, and the corrugated sheets were interleaved with alternate rows of aluminum mandrels and rubber mandrels. The aluminum mandrels served to conduct heat while the rubber mandrels served to distribute pressure throughout the stack. In a preferred form of the invention, all aluminum mandrels can be used which makes it possible to process the thermoplastic materials at high temperatures which would otherwise be detrimental to rubber. While aluminum has been disclosed as suitable, other high thermal conductive material may be substituted, such as copper.

The particular hex duct honeycomb pattern shown herein should not be considered as restrictive: the processes of this invention are generally applicable to ducted cores of various matrix patterns of which the honeycomb is representative.

The invention may be embodied in other specific forms without departing from the spirit and essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description; and all variations, substitutions and changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A method for forming a fiber reinforced honeycomb structure of open cells from a ribbon of thermoplastic resin impregnated fibercloth, said resin having a softening temperature, comprising:

providing a pair of forming wheels mounted for rotation to lie in the same plane with their outer perimeters touching at a tangent, each wheel having teeth of mating shape and corrugated for meshing together;

heating one of the wheels to above the softening temperature of said thermoplastic resin while maintaining the other wheel at a temperature substantially below said softening temperature;

training said ribbon between said wheels in full contact with said other wheel around a substantial arc thereon so that said ribbon makes contact with said heated wheel solely at the region of mesh between said wheels whereat it is softened and shaped by the contact forces between the wheels into a corrugated form and is thereafter immediately cooled by contact with said other wheel as it continues to travel along said arc in contact with said other wheel to form a shaped ribbon;

cutting the shaped ribbon into sheets;

stacking a plurality of shaped mandrels along with a plurality of said sheets configured in a manner to uniformly surround and separate each of said mandrels and to form a stack having a systematic matrix pattern of said corrugations;

applying pressure to said entire stack,

thereafter applying heat to said stack so as to thermal fusion bond the thermoplastic material together into a ducted pattern conforming to said corrugated shape and maintained by said mandrels;

thereafter cooling said stack and removing the pressure therefrom; and

thereafter extracting said mandrels from said stack to leave a ducted core structured in said systematic matrix pattern.

2. The method according to claim 1 wherein said corrugations are formed to be half-hexagon corrugations, said mandrels are hexagonal in cross section, and said corrugations and said mandrels are correspondingly sized such that, when said sheets are stacked together with said mandrels, adjacent pairs of said sheets are caused to abut at corresponding interfacial facets of said corrugations so as to form said core in a honeycomb pattern.

3. A method of producing a honeycomb core as in claim 1 in which

said fibercloth is a plurality of sheets of polyethersulfone foam impregnated woven glass cloth;

in which said stacking step includes interleaving said sheets with alternate rows of aluminum mandrels and rubber mandrels to form a honeycomb core assembly;

and in which said applying heat and pressure step includes applying said heat and pressure to said assembly within a temperature range from about 400 degrees F. to about 550 degrees F. to bond said polyethersulfone foam impregnated woven glass cloth half hex sheets together to form an integral structure.

* * * * *

US005662293A

United States Patent [19]

Hower et al.

[11] Patent Number: 5,662,293

[45] Date of Patent: Sep. 2, 1997

[54] POLYIMIDE FOAM-CONTAINING RADOMES

[76] Inventors: R. Thomas Hower; Stephen V. Hoang, both of c/o Marion Composites, 150 Johnston Rd., Marion, Va. 24354-3121

[21] Appl. No.: 435,171

[22] Filed: May 5, 1995

[51] Int. Cl.[6] B64C 1/00

[52] U.S. Cl. 244/133; 244/121

[58] Field of Search 244/133, 121; 343/708, 705

[56] References Cited

U.S. PATENT DOCUMENTS

2,167,972	8/1939	Crawford	244/133
2,614,059	10/1952	Cooper .	
2,728,702	12/1955	Simon et al.	244/133
3,063,654	11/1962	Youngren et al. .	
3,292,544	12/1966	Caldwell et al. .	
3,396,396	8/1968	Charlton et al.	343/708
3,637,166	1/1972	Nicholson et al.	244/121
3,713,961	1/1973	Copeland et al. .	
4,776,903	10/1988	Nordskog .	
4,896,164	1/1990	Burke et al. .	
4,943,594	7/1990	Ezawa et al. .	
5,323,170	6/1994	Lang	343/705
5,413,847	5/1995	Kishi et al. .	
5,429,326	7/1995	Garesché et al.	244/133

OTHER PUBLICATIONS

Donald J. Baker, Oct. 13–16, 1986 New Materials in Civil Aviation.

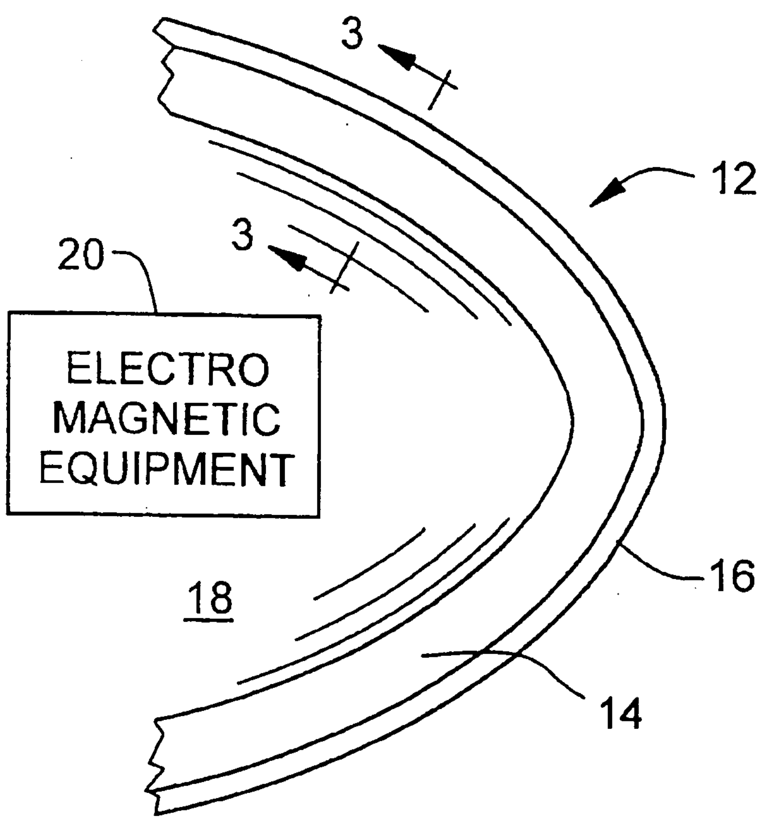
Aviation Week, Foam Plastic Is Lightweight Stiffener Oct. 27, 1952.

Primary Examiner—Andres Kashnikow
Assistant Examiner—Tien Dinh
Attorney, Agent, or Firm—Wood, Phillips, VanSanten, Clark & Mortimer

[57] ABSTRACT

A radome for protecting electromagnetic equipment includes a polyimide foam that preferably is a closed cell foam. The polyimide foam imparts improved impact and moisture resistance to the radome without adversely affecting electromagnetic transmission thereof.

15 Claims, 2 Drawing Sheets



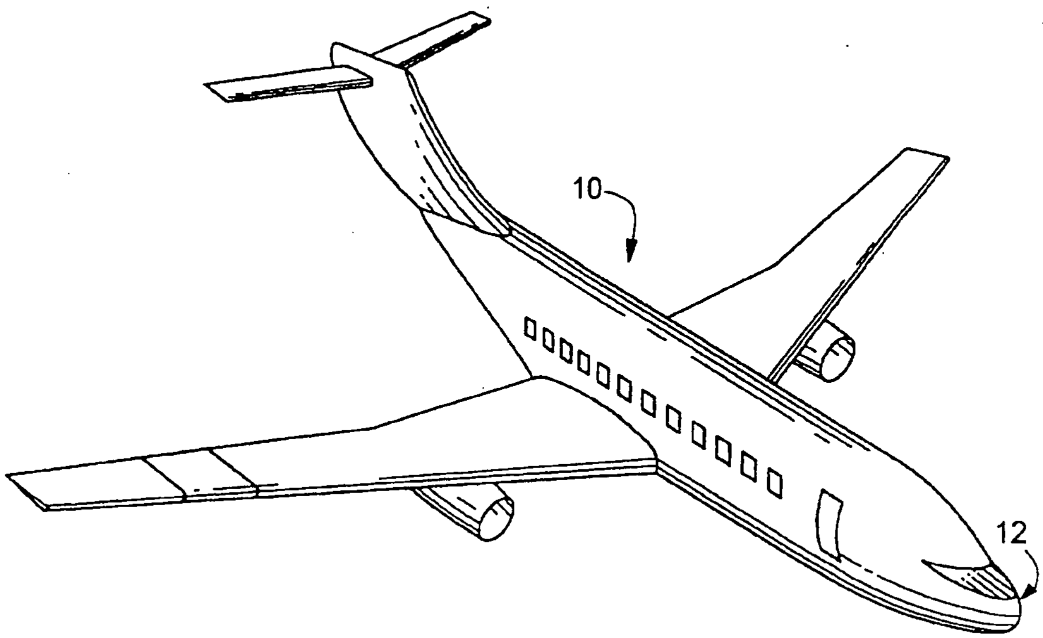


FIG. 1

FIG. 2

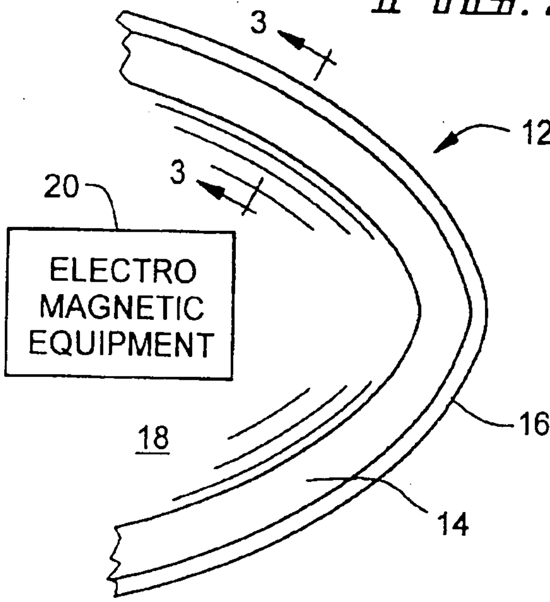


FIG. 3

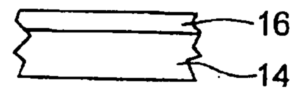
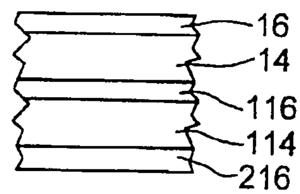


FIG. 4



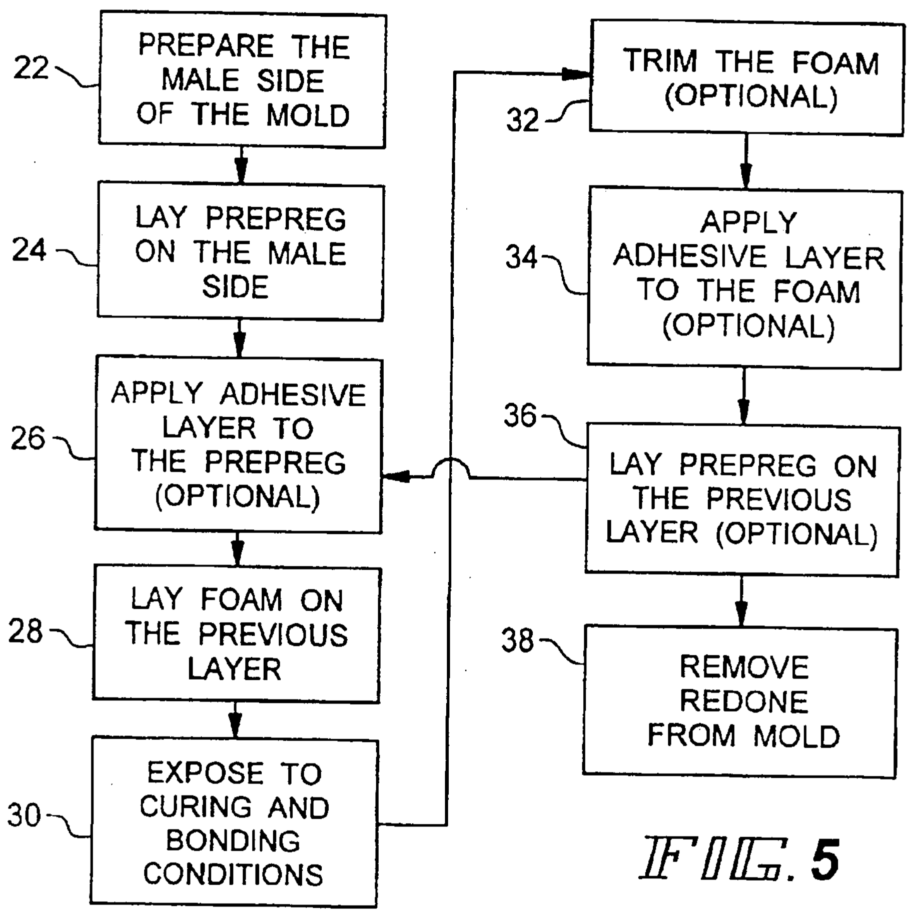


FIG. 5

POLYIMIDE FOAM-CONTAINING RADOMES

TECHNICAL FIELD

This invention generally relates to radomes. More particularly, the invention relates to polyimide foam-containing radomes.

BACKGROUND OF THE INVENTION

The word "radome" dates back to World War II and is derived from the words 'radar' and 'dome'. Originally, radome referred to radar transparent, dome-shaped structures used to protect radar antennas on aircraft. Over time, radome has come to mean almost any structure that protects a device, such as a radar antenna, that sends or receives electromagnetic radiation, such as that generated by radar, and which is substantially transparent to the electromagnetic radiation. The structure may be flat rather than dome-shaped and may be on an aircraft, the ground or a ship.

The term "radome", as used herein in its various grammatical forms, identifies any structure used to protect electromagnetic radiation equipment, e.g., radar equipment, that is aircraft, ground or ship based, unless a specific radome, e.g., or a nose radome of an aircraft, is identified.

A radome is an integral part of a radar system because the thickness of the radome and its properties affect the effectiveness of the radar and must be compatible with the specific properties of the radar set. Major design criteria of a radome include electromagnetic radiation transparency, structural integrity, environmental protection (e.g., protection from rain erosion and lightening strikes) and, especially for aircraft, an aerodynamic shape, and light weight. Economics also require that the cost should be as low as possible and the service life as long as possible. Successful radome design must balance all of the conflicting requirements. For example, the ideal shape of a nose radome for an aircraft from a electromagnetic radiation standpoint is hemispherical and as large as the aircraft will allow. A better aerodynamic shape, however, is ogival. A thick radome wall would have structural benefits, yet for optimum electromagnetic transmission the wall thickness must be chose as a factor of the radar wavelength. A thin, lightweight design may improve aircraft performance, save fuel, and reduce material cost but at the expense of decreased service life, increased maintenance costs, and/or increased product costs. Clearly, trade offs must be made.

Currently, a common type of radome is one having a fiberglass reinforced honeycomb core sandwich construction. The honeycomb core has an open-cell structure which encourages moisture intrusion that, as discussed below, can destroy the radome, and it has relatively poor impact resistance.

Static properties, finite element analysis (FEA), and testing traditionally have led aircraft designers to select the honeycomb core to construct the "best" radome. Although "best" is often defined as the lightest, stiffest and strongest core having the required electromagnetic properties, this approach is often inadequate, especially in impact/moisture critical environments, such as nose radomes and ship borne radomes. Radome repair data accumulated by the United States Federal Aviation Administration (FAA) indicates that about 85% of all honeycomb radomes are removed for moisture damage, and most air carriers confirm that their mean-time-between failures is substantially less than two years for some honeycomb radomes. Consequently, high maintenance costs, high inventory and questionable radar performance (due to moisture) occur.

Radomes fail when subjected to severe structural damage or degradation of electromagnetic radiation transmission. There are numerous ways for failure to occur in the hostile environment in which radomes must operate. Lightning strikes can cause microscopic pinholes or microcracks in a protective skin that covers the core. Static electricity on the outer surface of the radome can arc between the outer surface and the antenna or another electrically conductive surface to burn through the radome. Static burns are small, about the size of a pinhole or microcrack. High velocity rain or hail can cause core impact failure or "soft spots" in the radome which promote microcracking. Pinholes and microcracks are paths for moisture to enter the radome core. Rain or moisture causes further damage as it penetrates into the core through the pinholes or microcracks. During the flight of an aircraft, dynamic wind pressure pumps water through the pinholes or microcracks and deeper into the core.

Moisture in the core causes severe problems, especially if altitude or temperature changes result in multiple freeze/thaw cycles. The volume of the water expands by about 10% when it freezes causing it to exert a force against the core and skin. Repetitive freezing and thawing results in delamination, cracking and the like in the core that result in additional moisture paths and, if severe enough, radome failure. Water and ice are also detrimental to electromagnetic radiation transmission as their dielectric constant is on the order of 20 times greater than that of most materials used for sandwich construction radomes.

Another common type of radome used in aircrafts is the fluted core radome which was adopted to combat the moisture problem associated with the honeycomb core radome. The fluted core is a series of square fiberglass tubes. Hot air is blown into the tubes to deice the radome and blow water away from the region of the radome where electromagnetic transmission is critical. The fluted core has an undesirably high density (approximately 200 kg/m^3), which is over twice as dense as other radome core materials. A fluted core radome also weighs approximately 30% more than its honeycomb counterpart. The construction of a fluted core radome is very labor intensive, which leads to an expensive finished product. Furthermore, repairs are expensive and time consuming. These disadvantages are not acceptable to many radome users, especially since fluted core radomes eventually retain moisture in any event.

Yet another type of radome is the foam core radome. Radomes that used foamed in place polyurethane foam were popular in the 1950's, but the foam's tendency to crumble and poor fatigue and impact properties quickly gave "foam radomes" an unfavorable name. Other foams that allegedly are closed-cell (i.e. polymethacrylimide foam) actually have poor moisture absorption properties. This history of poor "foam radome" performance has hindered the development of other radomes using a better suited foam.

The use of a syntactic foam, i.e., foam containing glass microballons, in radomes is limited because the syntactic foam radomes are heavier than honeycomb radomes.

A radome that overcomes one or more of the aforementioned shortcomings is high desirable.

SUMMARY OF THE INVENTION

A radome of the present invention includes a polyimide foam that is preferably a closed-cell foam. The radome has a layer of the polyimide foam with a skin adjacent thereto to form a laminate structure.

Improved radomes that are less susceptible to moisture damage, are light weight and have good impact resistance are produced using the polyimide foam.

Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the preferred embodiments and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a radome of the present invention in a representative environment;

FIG. 2 is a fragmentary cross-sectional view of the radome;

FIG. 3 is a fragmentary cross-sectional view of the radome taken along line 3—3 of FIG. 2;

FIG. 4 is a fragmentary cross-sectional view of an alternative radome having two lagers of polyimide foam; and

FIG. 5 is a flow chart of a representative process for making the radome.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Although this invention is susceptible to embodiment in many different forms, there are described in detail herein, presently preferred embodiments of the invention. It should be understood, however, that the present disclosure is to be considered as an exemplification of the principles of this invention and is not intended to limit the invention to the embodiments described.

FIG. 1 illustrates a representative environment, shown generally as an aircraft 10, for a radome 12 of the present invention. The radome 12 is a nose radome positioned at the front of the aircraft 10. It should be understood that the present invention is also suitable for use as a radome in other environments such as ground based and ship based radar systems and that the radome is not necessarily a dome-shaped structure. It should also be understood that the radome is suitable for use with electromagnetic equipment in addition to radar.

FIG. 2 illustrates the radome 12 which is made of polyimide foam, that preferably is a layer 14, covered with a skin 16. The polyimide foam layer 14 is the core of the radome 12. The radome 12 defines a cavity 18 that receives and protects electromagnetic equipment 20. An antenna for radar is a representative piece of electromagnetic equipment.

FIG. 3 illustrates a cross section of the radome taken along line 3—3 of FIG. 2. The skin 16 is on an exterior surface of the polyimide foam 14.

In the embodiment illustrated in FIG. 4, the radome is a laminate made of two polyimide foam layers 14, 114 with skins 16, 116, 216 sandwiching adjacent polyimide foam layers 14, 114 therebetween.

The polyimide foam is rigid or semi-rigid and preferably is a closed-cell foam. In a closed-cell foam, each cell is entirely surrounded by a cell wall which inhibits the flow of fluids through the foam. In contrast, an open cell foam has individual cells are not completely surrounded by cell walls and fluid may pass between adjacent cells.

The cells of the polyimide foam preferably have a diameter in the range of about 0.5 to about 1 millimeters.

The density of the polyimide foam is preferably in the range of about 75 to about 85 kilograms per cubic meter.

The polyimide foam has a relatively high glass transition temperature which makes it well suited for high temperature applications such as those generated by high performance military aircraft. Preferably, the glass transition temperature is at least about 350° F.

The impact resistance of the polyimide foam is preferably in the range of about 1 to about 2 kilojoules per square meter.

The average dielectric constant is less than 1.4. The loss tangent is less than 0.02, preferably less than 0.007.

The polyimide foam is prepared by a conventional synthesis that, for example, reacts aromatic diamine functionality with an aromatic carboxylic acid functionality. Alternatively, the aromatic carboxylic acid functionality can be in its ester or anhydride form. When the polyimide is a polyetherimide, the foam is produced by a nucleophilic reaction between a phenolic salt functional group and a halo and/or nitro functionality. Polyimides and their synthesis are discussed in *Polyimides*, Edited by D. Wilson et al. published in the United States by Chapman & Hall, New York, N.Y., 1990, which is incorporated herein by reference.

Thermoset and thermoplastic polyimide foams are believed to be useful herein. Representative polyimide foams include the thermoset polyimide foams bismaleimides, acetylene-terminated polyimides, benzocyclobutene-terminated polyimides, poly-bis (allylnadic)imides and PMR-polyimides and the thermoplastic polyimide foams Skybond/Pyralin class (developers include Monsanto and DuPont), Avimid class (developed by DuPont), fluorinated polyimides (developers include TRW and Ethyl Corp.), LaRC-TPI (developed by NASA), Matrimid class (developed by Ciba-Geigy), polyetherimides (Ultem from General Electric), polyamideimides (Torlon developed by Amoco). Similar polyimide foams and mixtures of polyimide foams are also suitable. A preferred polyimide foam is the polyetherimide foam. A commercially available polyetherimide foam is R82.80 from Airex AG, Switzerland.

To achieve the desired shape of the radome, the polyimide foam is premade, e.g., in sheet form, and then formed into shape, as by thermoforming, during radome production. Alternatively, the polyimide foam is produced in-situ as by injection molding or spraying during radome production.

The skin(s) is conventional. Suitable skins are composites of a polymer and fiber reinforcement, e.g., a prepreg. A prepreg is a fiber reinforced mat, e.g., a fiberglass mat, preimpregnated with a polymer, e.g., an epoxy, that cures or hardens. One or more prepregs are used to make the skin. The orientation of the fibers of successive layers of the prepreg are arranged to optimize the mechanical properties of the radome.

Representative of the prepreg are conventional cyanate ester/epoxy fiberglass prepregs, 5575-2 cyanate ester resin/4581 Astroquartz III commercially available from Cytec, Anaheim, Calif., 7701 epoxy resin/7781 glass, commercially available from ICI Fiberite, and the like.

To facilitate bonding of the skin and polyimide foam, an optional adhesive layer is positioned therebetween. The adhesive is compatible with the resin of the prepreg and often is the same resin. Under pressure and elevated temperature, the adhesive permeates into the top layer of the foam to enhance bonding. The adhesive is optional when the prepreg contains sufficient resin to permeate into the foam.

Representative of the adhesive are AF143-2 epoxy adhesive commercially available from 3M, Minneapolis, Minn., M2555 cyanate ester adhesive commercially available from Cytec and the like.

FIG. 5 is a block diagram illustrating a preferred process for manufacturing radomes of the present invention. In the first block 22, the male side of the mold is prepared prior to laying one or more prepregs on the male side (block 24). An optional adhesive layer is applied to the prepreg (block 26)

prior to laying the polyimide foam layer on the previous layer (block 28) of prepreg or adhesive. The prepreg, adhesive (if present) and foam are subjected to curing and bonding conditions (block 30). These conditions include pulling a vacuum and exposure to elevated temperatures. To compensate for the shrinkage the foam can experience during curing and bonding, the foam layer applied in the step of block 28 can be thicker than necessary for the radome. If the foam layer even after shrinkage is too thick, it is trimmed to the proper thickness (block 32).

The following steps are optional and are only used if the radome is to have multiple skins or polyimide foam layers, otherwise, the radome is removed from the mold (block 38). An optional adhesive layer is applied to the polyimide foam (block 34) prior to an optional prepreg being laid on the previous layer (block 36). The steps represented by blocks 26–36 are repeated as necessary to build up the desired number of layers of the radome. When complete, the radome is removed from the mold (block 38).

The following example is provided by way of illustration, and not limitation.

EXAMPLE

A radome of the present invention was prepared according to the following procedure.

A male side of a mold was sanded smooth and conventionally prepared. A pin router was used to machine the 0.5 inch thick polyetherimide foam panel commercially available from Airex under the designation R82.80 to a thickness of 0.18 inches. Enough foam was cut to form two new pieces having the same shape as a form used to estimate the area where the lay up on the mold will take place. Two sheets of the polyetherimide foam were formed into shape with one sheet to be used to make the inner core and the other the outer core of a C-sandwich. Four layers of a cyanate ester/epoxy prepreg were laid up using a 0°/90°/90°/0° fiber orientation pattern. That is, the first and fourth layers had the same orientation, the middle second and third layers had the same orientation, and the second and third layers were rotated 90° from the orientation of the first and second layers. Vacuum debulking was used as necessary. A layer of AF143-2 adhesive commercially available from 3M was applied to the prepreg layers. The prepregs and adhesive layer were then vacuum debulked. One of the formed polyetherimide foam sheets was then laid in position. The mold, prepreg layers, adhesive layer and polyetherimide foam layer were bagged with no bleeding followed by curing in an autoclave at a temperature of 350° F.±10° F. using a temperature ramp rate of about 5° to about 10° F. per minute, a pressure of 20±5 pounds per square inch and full vacuum within the bag for a time period of about three hours once the cure temperature was reached. Cool down was performed at the rates of about 5° to about 10° F. per minute. The pressure and vacuum were not released until the temperature reached ambient, about 75° F. Then, one layer of the AF143-2 adhesive was applied followed by vacuum debulk. Ten layers of the cyanate ester/epoxy prepreg were laid thereon using a +45°/–45°/0°/90°/0°/0°/90°/0°/–45°/+45° pattern with a vacuum debulk being performed after every three layers. A layer of the AF143-2 adhesive was then applied followed by vacuum debulk. The second formed sheet of the polyetherimide foam was then applied. Curing was then performed using the above-described conditions and procedure. Then, a layer of the AF143-2 adhesive was applied followed by vacuum debulk. Three layers of the cyanate ester/epoxy prepreg were laid thereon using a

0°/90°/0° pattern followed by vacuum debulking. Cure was then effected using the above-identified conditions.

A radome of the present invention was then removed from the mold.

Radomes of the present invention are sufficiently strong to protect electromagnet equipment contained therein yet are substantially transparent to electromagnet radiation. The closed cells inhibit penetration of water into the polyimide foam/core to lessen the problems associated with water that penetrates a core. The high impact resistance of the polyimide foam enhances the ability of the radome to withstand impacts and maintain structural integrity. Further, the high impact resistance lessens the likelihood that moisture pathways will be produced upon impact.

We claim:

1. In a radome suitable for protecting electromagnetic equipment, the improvement comprising a closed cell thermoplastic polyimide foam which is moisture impervious and substantially transparent to electromagnetic radiation.

2. The radome of claim 1 wherein the thermoplastic polyimide foam is selected from the group consisting of Skybond/Pyralin class, Avimid class, fluorinated polyimides, LaRC-TPI, Matrimid class, polyetherimides and polyamideimides.

3. The radome of claim 1 further comprising a skin adjacent the thermoplastic polyimide foam.

4. The radome of claim 1 where the closed cells of the thermoplastic polyimide foam have a diameter in the range of about 0.5 to about 1 millimeters.

5. The radome of claim 1 wherein the thermoplastic polyimide foam has a glass transition temperature of at least about 177° C.

6. The radome of claim 5 wherein the thermoplastic polyimide foam has an impact resistance in the range of about 1 to about 2 kilojoules per meter squared.

7. A radome suitable for protecting electromagnetic equipment and moisture impervious, the radome comprising a closed cell thermoplastic polyimide foam, the closed cell thermoplastic polyimide foam selected from the group consisting of Skybond/Pyralin class, Avimid class, fluorinated polyimides, LaRC-TPI, Matrimid class, polyetherimides and polyamideimides.

8. The radome of claim 7 further comprising a skin adjacent to the thermoplastic polyimide foam.

9. The radome of claim 7 wherein the thermoplastic polyimide foam is a layer of thermoplastic polyimide foam and the radome further comprises a skin bonded to the thermoplastic polyimide foam.

10. The radome of claim 9 wherein the thermoplastic polyimide foam is at least partially impregnated with adhesive to bond the thermoplastic polyimide foam and skin.

11. The radome of claim 9 further comprising a second skin adjacent to the thermoplastic polyimide foam.

12. The radome of claim 7 wherein the thermoplastic polyimide foam is at least two layers of thermoplastic polyimide foam.

13. The radome of claim 12 further comprising at least one skin between adjacent thermoplastic polyimide foam layers.

14. The radome of claim 13 wherein the one of the thermoplastic polyimide foam layers is bonded to the skin prior to the other of the thermoplastic polyimide foam layers.

15. The radome of claim 7 wherein the thermoplastic polyimide foam is a semi-rigid or rigid foam.

* * * * *